Chapter 5

EXPERIMENTAL PROGRAMME

5.1 INTRODUCTION

To meet the objectives of the research, a detailed experimental programme was chalked out. The experimental study on the accelerated rehabilitation of rigid pavements in this research programme was restricted to the detailed investigation of different pavement concrete mixtures. In case of the major distresses of rigid pavements which warrant partial and full depth repair, the laying of new pavement in place of failed pavement becomes imperative. In situations like these the newly prepared pavement has to satisfy certain requirements like adequacy in strength and durability, early opening to traffic, cost effectiveness etc. It is concrete which often fulfils these requirements, though there are alternate materials for such purposes whose effectiveness is still being researched. Hence design of concrete mixtures to meet these specific needs is of paramount importance.

In this chapter the details of the ingredients of high early-strength concrete mixtures, mix proportioning, casting and curing techniques employed in the experimental programme are elaborated. The designed concrete mixtures were evaluated based on their fresh, hardened properties at early and later age and durability characteristics, in order to assess their suitability for the accelerated rehabilitation of rigid pavements. The entire experimental investigation was carried out in the “Concrete and Highway Materials” laboratory of Anjuman Institute of Technology and Management, Bhatkal, India. Experimental methodology adopted to assess the various properties of the concrete mixtures prepared for the research programme is also detailed in this chapter.
5.2 MATERIALS

Native aggregates (of Bhatkal town in Uttar Kannada district of Karnataka, India) ordinary tap water, three different types of cements manufactured by Indian cement industry and a commercially available non-chloride hardening accelerator were part of the several concrete mixtures, designed for the specific needs of the research programme

5.2.1 Cementitious Materials

Selection of cementitious material is extremely important in case of high early-strength concrete mixtures. OPC with its high pozzolanic nature has been in use to produce such mixtures. Cements like quick setting or early-strength cements are also tried for quick strength gain of concrete. Of late there is acute shortage of OPC and all government projects are made to suffer due to this shortage [28]. Hence need for supplementary cementitious materials, which can replace OPC partially or completely has increased substantially [29]. Fly ash and GGBS are the two by-products which are used as partial replacement to cement or to produce blended cements, the later method is found to be more effective. The use of fly ash and slag in fast-track pavement concrete is very limited, particularly the use slag [2]. The laboratory investigations on these by-products (used as partial replacement to cement or as part of blended cements) suggest that they can be employed in the production of pavement concrete [22, 23, 29, 30, 31, 32, 75, 76, 81, 84, and 87]. In India IS 456:2000, Code of Practice for Plain and Reinforced Concrete permits the use of PPC, Ministry of Road Transport and Highway (MORT&H) under its clauses 602 and 1000 does not permit its use, whereas IRC 15:2002, Code of Practice for Construction of Concrete Roads allows PPC conforming to IS 1489 [32]. The blended cements are found to be useful
in preventing delayed ettringite formation in concrete [9]. They are helpful in reducing heat of hydration in concrete which is seen as aging parameter in concretes [21]. It is worthwhile to compare the usefulness and the effects of blended cements in the high early-strength pavement concrete mixtures, with that of normal cement. Hence three very popular cements of India were included in the experimental programme, the details of which are mentioned in the next paragraph.

OPC 43 Grade, conforming to IS 8112:1989[93], PPC (approximate fly ash percentage 28-30), conforming to IS 1489 (Part I): 1991(fly ash based) [94] and PSC (approximate slag percentage 30-35), conforming to IS 455:1989[95], were used as cementitious materials, the properties of which are shown in Tables 5.1 and 5.2

<p>| Table 5.1 Physical characteristics of cementitious materials |
|---------------------------------|----------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Cement</th>
<th>Fineness (m²/kg)</th>
<th>Soundness Autoclave (%)</th>
<th>Setting Time (Min.)</th>
<th>Compressive Strength-28 Day (MPa)</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPC</td>
<td>230</td>
<td>0.8</td>
<td>95</td>
<td>230</td>
<td>45.20</td>
</tr>
<tr>
<td>PPC</td>
<td>305</td>
<td>0.7</td>
<td>105</td>
<td>240</td>
<td>37.50</td>
</tr>
<tr>
<td>PSC</td>
<td>240</td>
<td>0.8</td>
<td>110</td>
<td>245</td>
<td>35.40</td>
</tr>
</tbody>
</table>

<p>| Table 5.2 Chemical characteristics of cementitious materials |
|---------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Cement</th>
<th>Lime saturation factor (%)</th>
<th>MgO (%)</th>
<th>Ignition loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPC</td>
<td>0.8</td>
<td>1.2</td>
<td>1.45</td>
</tr>
<tr>
<td>PPC</td>
<td>0.8</td>
<td>1.3</td>
<td>1.40</td>
</tr>
<tr>
<td>PSC</td>
<td>0.85</td>
<td>1.3</td>
<td>2.20</td>
</tr>
</tbody>
</table>

5.2.2 Aggregates

Locally available, oven dried river sand conforming to grading zone III of IS 383:1970 [95] was used as fine aggregate (FA). Saturated surface dry angular aggregates (Crushed Granite) of size 20 mm and 10 mm, mixed in the ratio of 60:40,
were used as coarse aggregates (CA) such that the gradation after combining conformed to the grading limits for graded coarse aggregates as per IS 383:1970 [96]. The physical properties of the aggregates are listed in Table 5.3. The sieve analysis of the coarse aggregate is shown in Table 5.4

Table 5.3 Physical characteristics of aggregates

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Specific Gravity</th>
<th>Bulk unit weight (kN/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregate</td>
<td>2.60</td>
<td>15.77</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>2.71</td>
<td>15.49</td>
</tr>
</tbody>
</table>

Table 5.4 Sieve analysis of coarse aggregate

<table>
<thead>
<tr>
<th>IS sieve size (mm)</th>
<th>20 mm % passing</th>
<th>10 mm % passing</th>
<th>Combined gradation of 20 mm &amp; 10 mm in the ratio of 60:40</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>85.50</td>
<td>41.40</td>
</tr>
<tr>
<td>4.75</td>
<td>00</td>
<td>11.25</td>
<td>4.50</td>
</tr>
<tr>
<td>2.36</td>
<td>00</td>
<td>00</td>
<td>00</td>
</tr>
</tbody>
</table>

5.2.3 Admixture

Admixtures are obvious requirements to impart certain desirable attributes in concrete. Accelerators are the chemical admixtures which are categorized as set accelerators and hardening accelerators. Set accelerators reduce the setting time of concrete, whereas hardening accelerators give high early-strength. Accelerators primarily target aluminate, resulting in rapid loss of workability of fresh concrete.

High early-strength in concrete without heat treatment (an expensive proposition) is of greater significance in construction industry [51]. Hence the role and effects of accelerators in concrete are being researched. A number of specific requirements like type of cement, type of curing etc. are required to model the behaviour of accelerators [35]. Usually calcium chloride is used as hardening accelerator but as the concrete is prone to chloride attack due to calcium chloride, non-chloride hardening accelerators are being promoted by the manufacturers. There is limited application of non-chloride
hardening accelerator in the fast-track pavement concrete mixtures, particularly in India. Hence a non-chloride hardening accelerator was included as a chemical admixture in the experimental programme.

Commercial non-chloride hardening accelerator, manufactured by BASF Construction Chemicals (India) Private Limited was used to accelerate the hardening process of concrete mixtures at early age. The chemical admixture marketed as POZZOLITH 100HE is a free flowing colourless liquid, conforming to ASTM C-494 Type C, EN 934-2: T6 & T7 and IS 9103:1999 [97]. The typical applications of the admixture are: Precast/Prestressed concrete production, Concrete pavement repairs, Repairs of the industrial floors, Repairs of concrete slabs and flat members, Cold weather concreting and early de-stripping in cold weather [98]. The physical and chemical characteristics of the accelerator are listed in the Table 5.5

<table>
<thead>
<tr>
<th>Specific Gravity</th>
<th>pH</th>
<th>Chloride content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.26</td>
<td>6</td>
<td>&lt; 0.2%</td>
</tr>
</tbody>
</table>

* Data taken from the product brochure of the supplier

5.2.4 Water

Ordinary tap water was used for hydration process, whose pH was around 6.8. The water used was from the local reservoir, which is the major source of water supply for the town of Bhatkal.

5.3 CONCRETE MIX PROPORTIONING

Concrete mix proportioning was carried out using the revised Indian Standards guidelines, as given by IS 10262: 2009 [89]. There are certain changes in the revision. All requirements of IS 456: 2000 [99] are deemed as part of this standard. The workability requirements are expressed in terms of slump value of concrete which
were expressed in terms of compacting factor in the pre-revised standard. The quantity of admixture (chemical and mineral) is considered in the estimation of different ingredients of concrete, which was omitted in the pre-revised standard. Therefore according to the revised standard, volume of all in aggregate depends not only on the volumes of cement and water but also on the volume of admixture. Further, quantities of coarse aggregate and fine aggregate in terms of mass depend on volume of all in aggregate. Hence as the dosage of admixture is varied in a mixture, the quantities (mass) of aggregates also vary but in very small proportion.

Concrete mixtures of M40 grade were designed for PQC using native aggregates, OPC, PPC and PSC and varying dosage of accelerator. A total of 24 mixtures were designed in three different series, differentiated by the type of cement. The mixtures of these series were designated as OPC, PPC and PSC mixtures. The accelerator dosage was varied from 2 litres to 5 litres per cubic metre of concrete (7 dosages with an increment of 0.5 litre) following the guidelines of the manufacturer and the same was expressed as percentage of cement mass. Hence the change in the mass of cement per cubic metre of concrete resulted in change in the percentage dosage of accelerator, though the volume of accelerator remained the same. Few mix designs of different mixtures are illustrated in this section. Different trials of mix proportions for control mixtures of OPC, PPC and PSC were carried out to optimize cement content and water-cement ratio for the target strength. The cement content and water content selected for these three series of mixtures were in the range specified for typical PQC.
Mix proportioning for control mix of OPC (Reference IS 10262: 2009)

I  Stipulations for proportioning

a)  Grade designation: M40
b)  Type of cement: OPC 43 grade conforming to IS 8112
c)  Maximum nominal size of aggregate: 20 mm
d)  Maximum water-cement ratio: 0.45(from IS 456)
e)  Workability: 25 mm slump
f)  Exposure condition: Severe
g)  Method of concreting: Conventional
h)  Degree of supervision: Good
i)  Type of coarse aggregate: Crushed and angular in saturated surface dry condition
j)  Type of fine aggregate: Natural river sand in saturated surface dry condition
k)  Maximum cement content: 450 kg/m³

II Test data for materials

a)  Specific gravities
   Cement: 3.15, Fine aggregate: 2.60 and Coarse aggregate: 2.71
b)  Gradation of coarse aggregate: 20 mm and 10 mm, mixed in the ratio of 60:40
   such that the combined gradation conformed to the grading limits for graded coarse aggregates as per IS 383:1970
c)  Gradation of fine aggregate: Conforming to grading Zone III of IS 383:1970

III Target compressive strength $f'_{ck}$

$$f'_{ck} = f_{ck} + 1.65 \times s,$$
where $f_{ck}$ is characteristic compressive strength at 28 days and
$s$ is standard deviation. Taking $s$ equal to 5 N/mm$^2$, from Table 1 of IS 10262, $f'_{ck}$ is 48.25 N/mm$^2$.

**IV Water- cement ratio**

From different trials the water-cement ratio selected was 0.43 which is less than 0.45, hence O.K.

**V Selection of water content**

From Table 2 of IS 10262, the maximum water content for 20 mm aggregate and 25 mm slump is 186 litres per cubic metre of concrete, hence the same is adopted.

**VI Calculation of cement content**

Cement content = 186/0.43, which is equal to 432.56 kg/m$^3$

From Table 5 of IS 456, minimum cement content for severe exposure is 320 kg/m$^3$, hence O.K.

**VII Proportion of volumes of coarse and fine aggregate**

From Table 3 of IS 10262, volume of coarse aggregate for 20 mm coarse aggregate, water-cement ratio of 0.50 and fine aggregate of grading zone III is 0.64 m$^3$.

Adjustment for 0.43 water-cement ratio is +0.014, hence volume of coarse aggregate is 0.64 + 0.014 = 0.654 m$^3$.

Mix calculations

i) Volume of concrete = 1 m$^3$
ii) Volume of cement \( = \frac{\text{Mass of cement}}{\text{Sp. gravity of cement} \times 1000} \)
\[ = \frac{432.56}{3.15 \times 1000} = 0.137 \text{ m}^3 \]

iii) Volume of water \( = \frac{\text{Mass of water}}{\text{Sp. gravity of water} \times 1000} \)
\[ = \frac{186}{1 \times 1000} = 0.186 \text{ m}^3 \]

iv) Volume of all in aggregate \( = \{1 - (\text{II} + \text{III})\} = \{1 - (0.137 + 0.186)\} \)
\[ = 0.677 \text{ m}^3 \]

v) Mass of coarse aggregate \( = 0.677 \times 0.654 \times 2.71 \times 1000 = 1199.87 \text{ kg} \)

vi) Mass of fine aggregate \( = 0.677 \times (1-0.654) \times 2.60 \times 1000 = 609.030 \text{ kg} \)

Mix proportions for unit mass of cement are,

<table>
<thead>
<tr>
<th>Cement</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
<th>Water-cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.408</td>
<td>2.774</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Mix proportioning for PPC mix with admixture (Reference IS 10262: 2009)

I Stipulations for proportioning

a) Grade designation: M40

b) Type of cement: PPC conforming to IS 1489

c) Maximum nominal size of aggregate: 20 mm

d) Maximum water-cement ratio: 0.45(from IS 456)

e) Workability: 25 mm slump

f) Exposure condition: Severe

g) Method of concreting: Conventional

h) Degree of supervision: Good

i) Type of coarse aggregate: Crushed and angular in saturated surface dry condition
j) Type of fine aggregate: Natural river sand in saturated surface dry condition

k) Maximum cement content: 450 kg/m$^3$

II Test data for materials

a) Specific gravities
   
   Cement: 2.90, Fine aggregate: 2.60 and Coarse aggregate: 2.71

b) Gradation of coarse aggregate: 20 mm and 10 mm, mixed in the ratio of 60:40
   such that the combined gradation conformed to the grading limits for graded
   coarse aggregates as per IS 383:1970

c) Gradation of fine aggregate: Conforming to grading Zone III of IS 383:1970

III Target compressive strength $f_{ck}'$

$$f_{ck}' = f_{ck} + 1.65 \times s$$
where $f_{ck}$ is characteristic compressive strength at 28 days and
$s$ is standard deviation. Taking $s$ equal to 5 N/mm$^2$, from Table 1 of IS 10262,

$f_{ck}'$ is 48.25 N/mm$^2$.

IV Water- cement ratio

From different trials the water-cement ratio selected was 0.42 which is less than
0.45, hence O.K.

V Selection of water content

From Table 2 of IS 10262, the maximum water content for 20 mm aggregate and
25 mm slump is 186 litres per cubic metre of concrete, hence the same is adopted.

VI Calculation of cement content

Cement content = 186/0.42, which is equal to 442.85 kg/m$^3$
From Table 5 of IS 456, minimum cement content for severe exposure is 320 kg/m$^3$, hence O.K.

**VII Proportion of volumes of coarse and fine aggregate**

From Table 3 of IS 10262, volume of coarse aggregate for 20 mm coarse aggregate, water-cement ratio of 0.50 and fine aggregate of grading zone III is 0.64 m$^3$.

Adjustment for 0.42 water-cement ratio is +0.016, hence volume of coarse aggregate is 0.64 + 0.016 = 0.656 m$^3$.

**Mix calculations**

i) Volume of concrete $= 1 \text{ m}^3$

ii) Volume of cement $= (\text{Mass of cement}) / (\text{Sp. gravity of cement x 1000})$

$= (442.85)/ (2.90 \times 1000) = 0.153 \text{ m}^3$

iii) Volume of water $= (\text{Mass of water}) / (\text{Sp. gravity of water x 1000})$

$= (186)/ (1 \times 1000) = 0.186 \text{ m}^3$

iv) Volume of accelerator $= 0.002 \text{ m}^3$ (0.57 % of cement mass)

v) Volume of all in aggregate $= \{1- (\text{II+ III})\} = \{1- (0.153+ 0.186+ 0.002)\}$

$= 0.659 \text{ m}^3$

vi) Mass of coarse aggregate $= 0.659 \times 0.656 \times 2.71 \times 1000 = 1171.54 \text{ kg}$

vii) Mass of fine aggregate $= 0.659 \times (1-0.656) \times 2.60 \times 1000 = 589.409 \text{ kg}$

Mix proportions for unit mass of cement are,

<table>
<thead>
<tr>
<th>Cement</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
<th>Water-cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.330</td>
<td>2.645</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Mix proportioning for PSC mix with admixture (Reference IS 10262: 2009)

I Stipulations for proportioning

a) Grade designation: M40
b) Type of cement: PSC conforming to IS 455
c) Maximum nominal size of aggregate: 20 mm
d) Maximum water-cement ratio: 0.45(from IS 456)
e) Workability: 25 mm slump
f) Exposure condition: Severe
g) Method of concreting: Conventional
h) Degree of supervision: Good
i) Type of coarse aggregate: Crushed and angular in saturated surface dry condition
j) Type of fine aggregate: Natural river sand in saturated surface dry condition
k) Maximum cement content: 450 kg/m$^3$

II Test data for materials

a) Specific gravities
   Cement: 2.93, Fine aggregate: 2.60 and Coarse aggregate: 2.71
b) Gradation of coarse aggregate: 20 mm and 10 mm, mixed in the ratio of 60:40 such that the combined gradation conformed to the grading limits for graded coarse aggregates as per IS 383:1970
c) Gradation of fine aggregate: Conforming to grading Zone III of IS 383:1970

III Target compressive strength $f'_{ck}$

$f'_{ck} = f_{ck} + 1.65 \cdot s$, where $f_{ck}$ is characteristic compressive strength at 28 days and
$s$ is standard deviation. Taking $s$ equal to 5 N/mm$^2$, from Table 1 of IS 10262, 

$f'_{ck}$ is 48.25 N/mm$^2$.

**IV Water- cement ratio**

From different trials the water-cement ratio selected was 0.42 which is less than 0.45, hence O.K.

**V Selection of water content**

From Table 2 of IS 10262, the maximum water content for 20 mm aggregate and 25 mm slump is 186 litres per cubic metre of concrete, hence the same is adopted.

**VI Calculation of cement content**

Cement content = 186/0.42, which is equal to 442.85 kg/m$^3$

From Table 5 of IS 456, minimum cement content for severe exposure is 320 kg/m$^3$, hence O.K.

**VII Proportion of volumes of coarse and fine aggregate**

From Table 3 of IS 10262, volume of coarse aggregate for 20 mm coarse aggregate, water-cement ratio of 0.50 and fine aggregate of grading zone III is 0.64 m$^3$.

Adjustment for 0.42 water-cement ratio is +0.016, hence volume of coarse aggregate is 0.64 + 0.016 = 0.656 m$^3$.

Mix calculations

i) Volume of concrete = 1 m$^3$

ii) Volume of cement = (Mass of cement) / (Sp. gravity of cement x 1000)
\[(442.85) / (2.93 \times 1000) = 0.151 \text{ m}^3\]

iii) Volume of water = (Mass of water) / (Sp. gravity of water \times 1000)

\[(186) / (1 \times 1000) = 0.186 \text{ m}^3\]

iv) Volume of accelerator = 0.002 m³ (0.569 % of cement mass)

v) Volume of all in aggregate = \{I - (II+ III)\} = \{1 - (0.151 + 0.186 + 0.002)\}

= 0.661 m³

vi) Mass of coarse aggregate = 0.661 \times 0.656 \times 2.71 \times 1000 = 1175.01 \text{ kg}

vii) Mass of fine aggregate = 0.661 \times (1-0.656) \times 2.60 \times 1000 = 591.198 \text{ kg}

Mix proportions for unit mass of cement are,

<table>
<thead>
<tr>
<th>Cement</th>
<th>Fine aggregate</th>
<th>Coarse aggregate</th>
<th>Water-cement ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.335</td>
<td>2.653</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Tables 5.6, 5.7 and 5.8 give the mix proportions of OPC, PPC and PSC mixtures for varied dosage of accelerator respectively.

**Table 5.6 Mix proportions of OPC mixtures**

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Accelerator, %</th>
<th>Cement</th>
<th>FA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPC0</td>
<td>0</td>
<td>1</td>
<td>1.408</td>
<td>2.774</td>
</tr>
<tr>
<td>OPC 1</td>
<td>0.58</td>
<td>1</td>
<td>1.403</td>
<td>2.764</td>
</tr>
<tr>
<td>OPC 2</td>
<td>0.73</td>
<td>1</td>
<td>1.402</td>
<td>2.762</td>
</tr>
<tr>
<td>OPC 3</td>
<td>0.87</td>
<td>1</td>
<td>1.401</td>
<td>2.760</td>
</tr>
<tr>
<td>OPC 4</td>
<td>1.02</td>
<td>1</td>
<td>1.400</td>
<td>2.758</td>
</tr>
<tr>
<td>OPC 5</td>
<td>1.16</td>
<td>1</td>
<td>1.399</td>
<td>2.756</td>
</tr>
<tr>
<td>OPC 6</td>
<td>1.31</td>
<td>1</td>
<td>1.397</td>
<td>2.754</td>
</tr>
<tr>
<td>OPC 7</td>
<td>1.46</td>
<td>1</td>
<td>1.397</td>
<td>2.752</td>
</tr>
</tbody>
</table>

w/c ratio 0.43

**Table 5.7 Mix proportions of PPC mixtures**

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Accelerator, %</th>
<th>Cement</th>
<th>FA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPC0</td>
<td>0</td>
<td>1</td>
<td>1.335</td>
<td>2.653</td>
</tr>
<tr>
<td>PPC1</td>
<td>0.57</td>
<td>1</td>
<td>1.330</td>
<td>2.645</td>
</tr>
<tr>
<td>PPC2</td>
<td>0.72</td>
<td>1</td>
<td>1.330</td>
<td>2.643</td>
</tr>
<tr>
<td>PPC3</td>
<td>0.85</td>
<td>1</td>
<td>1.329</td>
<td>2.641</td>
</tr>
<tr>
<td>PPC4</td>
<td>0.99</td>
<td>1</td>
<td>1.328</td>
<td>2.639</td>
</tr>
<tr>
<td>PPC5</td>
<td>1.14</td>
<td>1</td>
<td>1.327</td>
<td>2.637</td>
</tr>
<tr>
<td>PPC6</td>
<td>1.28</td>
<td>1</td>
<td>1.326</td>
<td>2.635</td>
</tr>
<tr>
<td>PPC7</td>
<td>1.42</td>
<td>1</td>
<td>1.325</td>
<td>2.633</td>
</tr>
</tbody>
</table>

w/c ratio 0.42
### Table 5.8 Mix proportions of PSC mixtures

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Accelerator, %</th>
<th>Cement</th>
<th>FA</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSC0</td>
<td>0</td>
<td>1</td>
<td>1.339</td>
<td>2.661</td>
</tr>
<tr>
<td>PSC1</td>
<td>0.57</td>
<td>1</td>
<td>1.335</td>
<td>2.653</td>
</tr>
<tr>
<td>PSC2</td>
<td>0.72</td>
<td>1</td>
<td>1.334</td>
<td>2.651</td>
</tr>
<tr>
<td>PSC3</td>
<td>0.85</td>
<td>1</td>
<td>1.333</td>
<td>2.649</td>
</tr>
<tr>
<td>PSC4</td>
<td>0.99</td>
<td>1</td>
<td>1.332</td>
<td>2.647</td>
</tr>
<tr>
<td>PSC5</td>
<td>1.14</td>
<td>1</td>
<td>1.331</td>
<td>2.645</td>
</tr>
<tr>
<td>PSC6</td>
<td>1.28</td>
<td>1</td>
<td>1.330</td>
<td>2.643</td>
</tr>
<tr>
<td>PSC7</td>
<td>1.42</td>
<td>1</td>
<td>1.329</td>
<td>2.641</td>
</tr>
</tbody>
</table>

w/c ratio 0.42

### 5.4 MIXING AND CASTING OF SPECIMENS

Laboratory Drum-type, electrically operated mixer was used for mixing the ingredients of the concrete mixtures and table vibrator was used for the purpose of compaction.

Cube specimens of standard size (150 mm) were cast for the purpose of compression, permeability and chemical tests. 864 cube specimens of different mixtures (288 in each series) were cast for compression tests of mixtures at early age and at full maturity. 144 cube specimens of different mixtures (48 in each series) were cast for testing permeability at full maturity and equal numbers of cube specimens were cast for chemical test also. 864 (288 in each series) beam specimens of different mixtures, of size 100 mm x 100 mm x 50 mm were cast for flexure tests of the mixtures at early age and at full maturity.

### 5.5 CURING

Conventional water curing is always found to be more suitable for effective hydration. But in areas that suffer from scarcity of water, alternative curing techniques are explored. For pavement concretes curing compounds are found to be practically suitable due to the ease with which they can be used. These curing compounds produce effective membrane on the exposed surfaces of concrete structures when
applied either by hand brushing or by spraying. The curing compounds are either acrylic based or water based. The acrylic based curing compounds are found to be more effective [67]. The strength of concrete produced with fly ash and slag is more sensitive to poor curing than that of conventional concrete [62]. Hence to study the effects of methods of curing on strength and durability of high early-strength pavement concrete produced with different cements a curing compound was included as part of the research.

Two curing methods were adopted for the laboratory specimens, namely conventional water curing and curing by the use of curing compound. Half of the total laboratory specimens (432 for compression test, 72 for permeability test, 72 for chemical test and 432 for flexure test) were subjected to conventional water curing and remaining half to membrane curing. The curing compound used in the study was wax based, manufactured by BASF Construction Chemicals (India) Private Limited with a brand name of Masterkure107i (conforming to ASTM C309 Type II Class A and BS 7542: 1992), whose typical properties are given in Table 5.9 [100]. The curing compound was applied to all the sides of the specimens by ordinary paint brush of size 10 cm, after a period of 4 to 5 hours when the top surface of the specimen appeared dry and free of surface water as per the recommendation of American Concrete Institute [20].

Table 5.9 Properties of curing compound**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Relative density</th>
<th>Dry film appearance</th>
<th>Loss of water (ASTM C156)</th>
<th>Day light reflectance (ASTM E1347)</th>
<th>Drying time</th>
</tr>
</thead>
<tbody>
<tr>
<td>White liquid</td>
<td>1 ± 0.05 @ 25ºC</td>
<td>White solar reflective</td>
<td>&lt; 0.55 kg/m²</td>
<td>&gt; 60 %</td>
<td>Less than 3 hours</td>
</tr>
</tbody>
</table>

**Taken from the product brochure of the supplier
5.6 TESTS ON FRESH CONCRETE

All the concrete mixtures were tested by Slump, Compacting Factor and Vee-Bee tests in accordance with IS 1199:1959 to assess the workability [101]. Slump test is the simplest test which can be performed in the field and in the laboratory. If the workability of concrete is very low and strict quality control is required like in case rigid pavements, Compacting Factor test is better choice for workability [99]. The working principle of this test is to determine the degree of compaction achieved by a standard amount of work done by a given concrete when it is allowed to fall through a standard height. The degree of compaction is called Compacting Factor which is the measure of the ratio of density achieved in the test by means of partial compaction to the density of fully compacted concrete. IS 10262 in its first edition had Compacting Factor as the workability requirement for fresh concrete but looking into the popularity and simplicity of Slump test, the standard has specified Slump test to decide and assess the workability of fresh concrete. Vee-bee test is also suited for concretes with low workability. It measures the time required to change the shape of a given fresh concrete from frustum of a cone to cylinder, when the fresh concrete is subjected to vibration in a standard apparatus. Even a slightest change in the workability of concrete can be recorded by this test. The test is ideally suited to for the mixtures that are insensitive to the slump test.

5.7 TESTS ON HARDENED CONCRETE

5.7.1 Compressive Strength Test

It is by and large the most common test for quality compliance of concrete, owing to its simplicity. According to IS 456-2000[99], it is the test which is used to grade the concrete. Many construction agencies consider compressive strength for quality
compliance. The test is generally performed on hardened cube and cylindrical specimens. It is uniaxial test where the compressive load is progressively increased till the specimen fails, which generally occurs in 2 to 3 minutes [54]. In this experimental programme this test was performed on the concrete cube specimens of size 150 mm at early age and at full maturity in accordance with IS 516-1959 [102]. In the test, the cube specimens were placed between the platens of the compression-testing machine and compressive load was applied gradually until the specimens failed. The compressive strength of the concrete was calculated as

\[
\text{Compressive strength} = \frac{\text{Compressive load at failure}}{\text{Cross sectional area of the specimen}}.
\]

Compression test on cube specimens of OPC, PPC and PSC concrete mixtures without accelerator and with varied dosage of accelerator (2 litres to 5 litres per cubic metre of concrete with an increment of 0.5 litre), cured with water and alternatively with curing compound, was performed at 1, 2, 3, 5, 7 and 28 days of curing. Average strength of 3 cubes of a given mixture at a given curing age was considered for reporting the strength. The compression testing machine used for the tests had a capacity of 2000 kN.

5.7.2 Flexural Strength Test

Flexural strength is the design criterion for the rigid pavements. But usually concrete mix proportions’ guidelines are based on the compressive strength. Wheel loads and volume change in the concrete are responsible for tensile stresses in rigid pavements. High tensile stresses due to bending (flexural stresses) may develop in the concrete slab if the subgrade support is inadequate. Stresses due to volume change may be significant and are additive to the wheel load stresses [103]. Hence, though
the pavement concrete mixtures are designed based on the compressive strength, it is always worthwhile to assess their flexural strength. Flexural strength of concrete is mentioned in terms of modulus of rupture, which is the maximum flexural stress at rupture. Centre-point loading and Third-point loading (also known as Two-point loading) are the two types of loading considered for the assessment of flexural strength. In case of Centre-point loading test, the maximum fiber stress will be at the centre of the beam where the bending moment is maximum, whereas in Third-point loading test it may be at any section (which is weak in resisting the stress) in the middle-third region of the beam where the bending moment is constant (no shear force) and maximum. Hence the Third-point loading is generally specified for the flexural strength of concrete.

In this experimental programme the flexural strength tests were performed on the concrete beam specimens at early age and at full maturity in accordance with IS 516-1959 [102]. A 100 kN capacity machine was used for flexural strength tests. Flexural strength test on beam specimens of OPC, PPC and PSC concrete mixtures without accelerator and with varied dosage of accelerator (2 litres to 5 litres per cubic metre of concrete with an increment of 0.5 litre), cured with water and alternatively with curing compound, was performed at 1, 2, 3, 5, 7 and 28 day of curing. Average strength of 3 specimens of a given mixture at a given curing age was considered for reporting the strength.

The standard sizes of the beam specimens are 150 mm x 150 mm x 700 mm and 100 mm x 100 mm x 500 mm. Smaller of these two sizes can be used if the maximum size of the aggregate in the concrete is not exceeding 20 mm. In this experimental investigation smaller beam specimens were tested by applying progressively
increasing load at the rate of 1.8 kN / min till the specimens failed. The modulus of rupture in MPa was calculated by equations 5.1 and 5.2

Modulus of rupture

\[ f_b = \frac{P l}{b d^2} \]  \hspace{1cm} 5.1

if \( a \) is greater than 133.33 mm and

\[ f_b = \frac{3 P a}{b d^2} \]  \hspace{1cm} 5.2

if \( a \) is lesser than 133.33 mm but greater than 110 mm ,

where

\( P \) is load at failure of the specimen in N;

\( l \) is the center to center distance between the supports of the beam in mm;

\( a \) is the distance of the crack from the nearest support, measured on the centre line of the tensile side of the specimen in mm; and

\( b \) is the width of the specimen in mm and \( d \) is the depth of specimen in mm, measured at the point of failure.

If \( a \) is less than 110 mm, the results of the test are discarded.

**Figure 5.1** Schematic sketch of Flexure test (Third-point loading)
5.7.3 Permeability Test

5.7.3.1 Significance

One of the important properties that affect the durability of the concrete is its permeability [99]. Permeability of concrete has much wider and direct repercussion on the durability than water-cement ratio [103]. The permeability of concrete largely depends on the size and volume of interconnected capillary pores of the cement paste, and also on the magnitude of microcracks that exist at the interface of aggregate-cement paste and within the cement paste [86]. Strength and permeability of concrete are related to each other through capillary porosity; hence the factors that influence strength should also influence the permeability [54]. But this may not be true in all the cases. The permeability of concrete is not routinely measured, because the experiment is difficult, where a pressure gradient over a concrete specimen has to be established, which can take few days and during this period there is high risk of leaks under the pressure which are difficult to identify [104]. But the assessment of permeability of pavement concrete, particularly of fast-track pavement concrete assumes greater significance due to the type of forces and the atmospheric agents the pavement concretes are subjected to. Further, it is the permeability of the concrete that leads to volume change in concrete, the volume change results in cracks and the cracks promote the permeability and hence this process is cyclic and continues till the eventual failure of the concrete [103]. Hence permeability test was included to study durability properties of concrete mixtures.

5.7.3.2 Working Principle

The working principle of the permeability test on concrete is to subject hardened concrete specimen to a known hydrostatic pressure from one side and to measure the
quantity of percolating water from the specimen during a given interval of time. By knowing the quantity of percolated water, size of the specimen, hydrostatic pressure and duration of the test, the coefficient of permeability of concrete \((K)\) which is also known as the hydraulic conductivity can be determined.

### 5.7.3.3 Apparatus and Procedure

The permeability tests on the hardened concrete specimens were conducted based on the guidelines of IS 3085-1965[105]. The apparatus for the test had

1. Three permeability cells to keep concrete specimens. The cells had ledge at the bottom for retaining the specimen, top and bottom plates and a sheet metal funnel which could be secured to the cell.
2. A water reservoir (Pressure chamber) which had pressure regulator and gauges to record the inlet. (Maximum of 21 kg/cm\(^2\)) and outlet (maximum of 17 kg/cm\(^2\)) pressures of the water.
3. An air compressor of capacity 20 kg/cm\(^2\) to supply the compressed air.
4. One stand fitted with T-connector, valves and one pressure gauge.
5. Graduated measuring jars.

The procedure for the test is as follows.

i) Clean the hardened cube specimens with a stiff wire brush to remove all laitance. Chisel the end faces slightly and dry the surface of the specimen.

ii) Calibrate the reservoir as per IS 3085-1965[105].

iii) Centre the specimens in the cell and allow the lower end to rest on the ledge. Seal the annular space between the specimen and the cell with a suitable sealant. For this purpose soak cotton or hemp in the molten sealant.
and tightly caulk the annular space for a depth of 10 mm. Carefully fill the remaining space with the molten sealant up to the top level of the specimen. Any drop in the level due to cooling of the specimen should be made up by adding additional sealant. Test the seal by applying a pressure up to 2 kg/cm$^2$ as per the instruction of the standard.

iv) After a satisfactory seal, securely bolt the bottom plate and funnel in position. Connect the cells to the pressure chamber after properly mounting them on the stand. Connect the pressure chamber to the air compressor.

v) Note down the test temperature (preferable temperature is 27±2 °C). Keep the measuring jars below the cells for collecting percolating water.

vi) Fill the pressure chamber and cell assembly with water.

vii) Start the compressor and apply the required pressure to the water column (5 to 15 kg/cm$^2$ depending on the quality of concrete) with the help of pressure regulator.

viii) Collect the water percolating out of the specimen. Continue the test for 100 hours after the steady state of flow is achieved. Note down the quantity of water percolating over entire period of test after the steady state has been reached.

The coefficient of permeability $K$ shall be calculated by equation 5.3

\[
K = \frac{Q}{(AT)(H/L)}
\]  

5.3

$K = \text{Coefficient of permeability in cm/sec;}

Q = \text{Quantity of water in millilitres percolating over the entire period of the test after the steady state has been reached;
\[ A = \text{Area of the specimen face in cm}^2; \]

\[ T = \text{Time in seconds over which Q is measured; and} \]

\[ \frac{H}{L} \text{ is the ratio of pressure head to thickness of the specimen, both expressed in the same unit.} \]

In this experimental programme, two types of sealants were tried for sealing the annular space between the specimens and cells. Initially a mixture of honey wax and rosin was tried which could withstand a maximum pressure of 6 kg/cm\(^2\). As this pressure was insufficient for PQC, bitumen was tried which proved to be an effective sealant. The tests were performed at a constant pressure of 12.5 kg/cm\(^2\). The entire permeability test programme was carried out in three winter seasons (November to February); where the average room temperature was almost equal to the test temperature.

Permeability test on cube specimens of OPC, PPC and PSC concrete mixtures without accelerator and with varied dosage of accelerator (2 litres to 5 litres per cubic metre of concrete, with an increment of 0.5 litre), cured with water and alternatively with curing compound, was performed at 28 day of curing. Average coefficient of permeability of 3 specimens of a given mixture was calculated. The permeability at early age of concrete mixtures was not assessed as it keeps on varying during the process of hydration and hence the permeability of fully matured concrete is the true indicator of its durability.
Concrete structures in general and concrete roads in particular should withstand different weather conditions. In country like India where many regions experience moderate to heavy rains, the concrete roads of such regions should be able to withstand the detrimental effect of heavy rains. With increase in the environmental pollution levels, especially in industrial cities, even the rains are prone to pollution. With unabated growth of industries and increase of carbon emissions, the occurrence of acid rains (which are characterized by lower pH values) is not confined to the urban areas; even rural areas are affected by this man made phenomenon [54].

With possible increase in the frequency of occurrence of acid rains in the near future, the PQC for both construction and rehabilitation should withstand the ill effects of acid rains. In case of acid attack, protons from the acid enter the concrete and dissolve solid hydration products in the binder; even the aggregates are vulnerable to the attack [106, 107]. Continued attack of acid rain may result in progressive loss of strength, cracking of the concrete, reduction in concrete mass and eventually structural failure of concrete [107]. Hence testing of high early-strength PQC mixtures for chemical resistance is warranted.
5.7.4.2 Procedure

There are several methods to determine chemical resistance of concrete. In this experimental programme resistance of concrete mixtures to sulphuric acid was evaluated. The resistance to sulphuric acid was tested by immersing the hardened concrete specimens in an acid solution of known pH for 90 days after subjecting them to a longer curing period, which is usually 90 days [108]. Alternatively the test can commence after concrete specimens achieve full maturity which is after 28 days of curing [109].

Sulphuric acid resistance tests on all water-cured and membrane-cured cube specimens of OPC, PPC and PSC concrete mixtures, without accelerator and with varied dosage of accelerator (2 litres to 5 litres per cubic metre of concrete with an increment of 0.5 litre) were performed by finding the average mass losses and compressive strength losses of three specimens of a given mixture and for a given method of curing after immersing the fully matured specimens (moist-cured for 28 days) in 1 per cent sulphuric acid solution for 90 days.